

Interactive comment on “Dynamics of ionic species in Svalbard annual snow: the effects of rain event and melting” by Elena Barbaro et al.

Anonymous Referee #2

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General comments

The purpose of this study is to investigate the effects of the rain and snowmelt on ionic species in Svalbard snow. The authors carried out intensive snow-pit observations and snow sampling for about two months on a glacier in Svalbard. They present valuable data obtained from daily snow pit sampling, which requires substantial effort. However, I'm not convinced if their observations, sampling and data analyses were performed adequately to reach their goal. This might be partly due to many typographical/grammatical errors and lack of detailed description, which make some parts of the manuscript hard to understand.

The manuscript gives only qualitative information on different behaviours of biogenic and sea spray ions and elution sequence of ions, without a firm basis.

Without analysing how much melt (and melt/rainwater percolation) caused how much elution of ions, the manuscript doesn't add much to the previous studies. Such quantitative analysis needs calculation of mass balances of H₂O and ions in each layer of the snowpack, as was done by e.g. Suzuki (1982, https://www.jstage.jst.go.jp/article/rikusui1931/43/2/43_2_102/_article/-char/en). But the manuscript gives no quantitative information about the amount of fresh snow deposited each day and amount of ions contained in it, nor how much ablation (melting etc.) took place each day. Although the data are unique and important, I don't think the manuscript in its current form provides enough new insight on the effects of the rain and snowmelt for publication in the Cryosphere.

Specific comments

Lines 67-69. I couldn't understand this sentence. I don't understand the definition of the seasonal snow layer. I don't think we usually call the snow layer accumulated above the equilibrium line "seasonal snow layer". What do you mean by "ground"?

Line 69. Does "seasonal snow layer" mean "seasonal snow cover"?

Line 77. I think temperature, as well as temperature gradient, is important.

Line 111. I don't think that snow on a glacier can be called "seasonal snowpack".

Line 118. A reference for the annual precipitation data is necessary here.

Lines 118-122 Where in Ny-Alesund area were the annual precipitation and temperature measured? I think this should be clarified because these values vary with elevation and may vary due to orographic effects.

Line 134. How deep were the plastic poles dug into the glacier ice? Were the poles stable during the whole observation period, not affected by the snowmelt and rain? If the poles moved due to snowmelt or rain, how did the authors correct snow depth readings from the poles?

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Lines 141-142. What were the daily loss or gain of snow? I think this information is very important, although the manuscript only gives average daily standard deviations of accumulation.

Lines 144-146. I couldn't understand "Before sampling the snow, surface was scratch". If the surface snow was removed and not collected as a sample, the authors should clarify from what depth (with respect to the snow surface) the samples were taken. I think it is important to collect a sample from the very surface of the snowpack because it is the snow most strongly affected by rain and melting. Furthermore, if new snow deposited after the previous sampling, the newly added amounts of H₂O and ions to the snowpack can be measured with this surface sample. This is important to calculate mass balances of H₂O and ions. Each day the authors collected only 10 samples from a depth (from the snow surface) which is not written in the manuscript. I'm not convinced if this sampling resolution is enough to trace the temporal changes of same snow layers within the snowpack. To trace the temporal changes of same layers, one should collect samples at a higher resolution or collect samples from the same layer defined by visual stratigraphy (please see Suzuki et al., 1982). I think until heavy snowmelt occurs, one can usually trace a same snow layer by visual stratigraphy of a snowpack. As the thickness of each snow layer within a snowpack changes due to snow densification even if there is no rain events or fresh snow deposition, the authors might have collected snow from different layers on different days, although each sample was collected from a same depth (with depth correction).

Lines 190-193. What is the elevation of AWIPEV. The air temperature at AWIPEV could be different from that at the sampling site. If the manuscript uses the air temperature data at AWIPEV, the temperature difference should be at least estimated.

Lines 199-201. If the daily precipitation was measured near the sea level, it could be different from that at the sampling site. Some part of the rain at the meteorological station could have precipitated as snow at the sampling site at 270 m a.s.l.

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Line 232 gives the impression that visual stratigraphy was observed. But later, Line 288 reads that only hardness was recorded. Was visual stratigraphy observed? Visual stratigraphy is very important to deduce the degree of melt effects.

Line 240. Is “close to the melting point” correct? Isn’t this “at the melting point”?

Lines 245-261. I couldn’t understand how the statistical analysis was performed to investigate the effects of the rain event and snowmelt. More detailed information on statistical analysis is required. Why was the snowpack divided into three levels for the biogenic ions and four levels for other ions? I couldn’t see from Figs. 2 and 3. How were p-values calculated and what do they mean?

Line 251. How was the concentration data interpreted using the “logarithmic scale” ?

Line 267. Is the data correct? Isn’t it 16th April?

Line 272. Why “but”?

Line 274. Does Fig.2 mean Fig. 1?

Lines 275-286. I’m concerned about the LWC measurement after the rain event. Was the measurement carried out adequately at the depths other than 50cm? Meltwater often percolates through a water channel. If this happens, some part of the snowpack contains liquid water, but other parts at the same depth may not. Have the authors checked the horizontal inhomogeneity in liquid water content? As the authors dug a snow pit every day, they should have observed visually how the meltwater percolated and/or affected the snowpack.

Line 294. How did the authors conclude that this layer consists of the early snow accumulated during late autumn or early winter? Line 124 reads that average snow depth of 2.5 m at the upper part of AAB. What is the average snow depth at the sampling site? If the average snow depth at the sampling site is similar to that at the upper part of AAB (~2.5m), is the layer at 1 m depth really the snow accumulated in late autumn or early winter? Isn’t 1m too shallow?

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Line 298. What does “re-allocated” mean?

Line 314. What does “both” mean?

Lines 313-320. Although the authors divided the ions into two groups, I’m not convinced about the grouping. Some of the ions have different sources. For example, nitrate could originate from anthropogenic NO_x as well as from biogenic activities. Sulphate could originate from DMS emissions (i.e. biogenic activities), sea spray and anthropogenic SO_x. Different sources of an ionic species could have different chemical forms, which could result in a difference in elution sequence.

Line 329. Ions are not compounds.

Lines 328-360. Hard to understand. Descriptions on temporal changes in each ion do not seem to correctly correspond to Figures and Tables. For example, although Lines 328-329 read that MSA showed rather homogeneous concentrations until the end of April, Table S1 shows very different values for three different depth intervals. There are other similar discrepancies between the text and Figures/Tables. The color plots in Figs. 2 and 3 are not easy to understand. Line graphs showing values are necessary here. The authors argue that concentrations of biogenic ions increased in upper layers of the snowpack due to the input of primary production. Supporting evidence is necessary to show that the primary production did increase, air masses with high concentrations of biogenic species did reach AAB, and that these ions did penetrate into the snowpack is necessary. I also wonder why sea spray species did not increase. If air masses from the open sea brought marine biogenic species to AAB, they could have also brought sea spray species. The reason to explain the difference is needed. Why were median concentrations, not averages, used? The authors discuss increases and decreases. Are they statistically significant? There should be spatial variability in ion concentrations in a snowpack. As concentrations were measured in different snow pits on different days, initial spatial variability should be taken into account to discuss temporal variability. I think authors can do that using the daily data from P1.

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Line 333. Affected by what?

Lines 363-365. As mentioned above, this part needs more detailed explanation.

Line 369. Where were the values 15.1mm and 15mm recorded? The values would be different at the sampling site.

Lines 387 and 391. Line 387 reads that C5 and C2 are biogenic organic ions, but line 391 reads that these ions originated from continental pollution sources. This is confusing.

Line 400. Does “temperate” mean “temperature”?

Lines 405-406. What does “an improve of concentrations” mean?

Lines 407-420. As stated above, I couldn’t understand how the elution sequences were derived.

Lines 421-434. Unless ion concentrations in the rain and fresh snow deposited on the snow surface are known, I think it is difficult to discuss the causes of the changes in ion concentrations.

Lines 440-442. I couldn’t understand English here.

Line 453. Fig.5?

Line 480. How is “From a millennial scale” relevant to this study?

Was the density of each snow layer measured? Density measurement is essential for mass balance calculations.

Fig. 1. First, figure title, a, b, and c are missing. Second, the color plots are not easy to understand. In the uppermost plot, value zero is very important, but difficult to see. In the lowermost plot, the melting point is very important, but difficult to see. Line plots showing changes in values are needed here. Third, the manuscript needs to explain how the lowermost plot was made from the 11 temperature probes.

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Fig. S1. Visual stratigraphy should be presented. At least new snow and ice layers should be marked.

There are also other typos and errors that I haven't pointed out.

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